

Motivation and Goals

Motivation: Minimizing the fuel required for orbital transfers and corrections directly translates into more mass available for instruments and reduced costs. The initial guess algorithm, developed here for the MMS mission, can be applied to other missions as well.

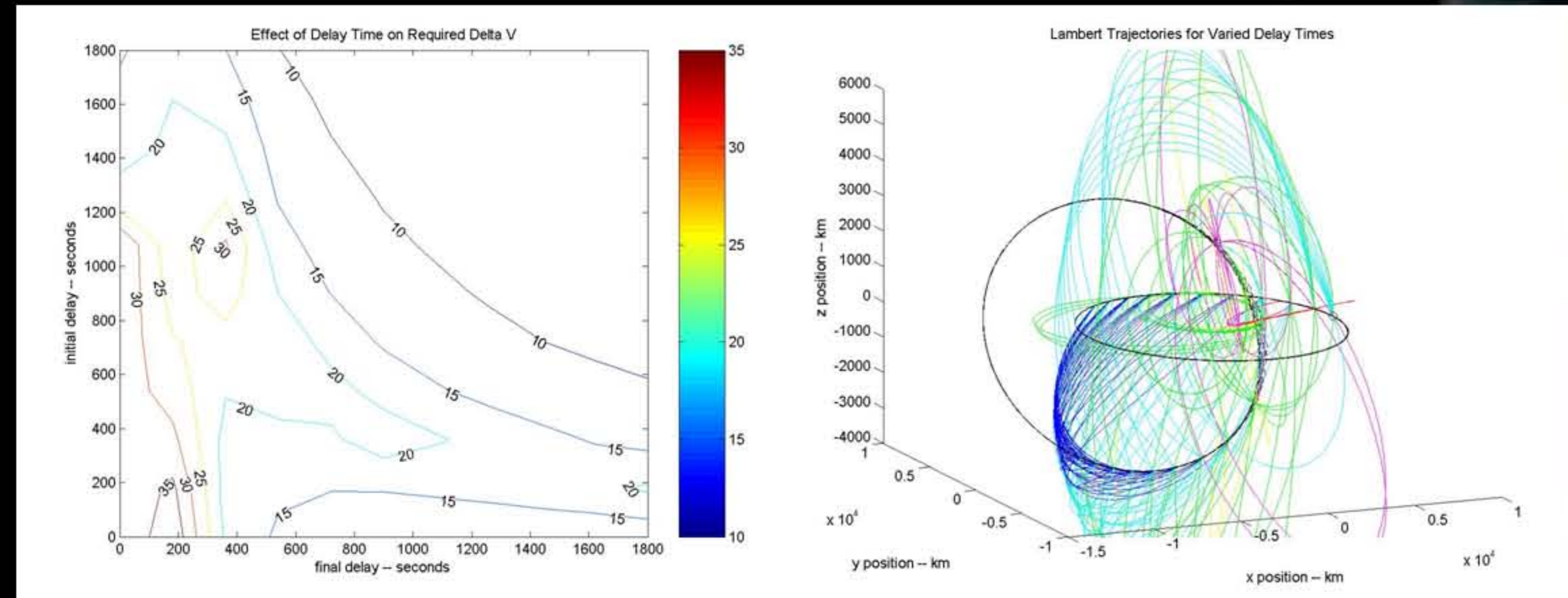
My Goal: To develop and implement an algorithm to create near-optimal guesses for minimum fuel orbital rendezvous. The algorithm should run quickly and produce guesses within 20% of the optimal solution.

Minimum Fuel Rendezvous

Key Concepts: Six elements and a time specify a satellite's location. A rendezvous involves traveling from set of orbital elements to another within a specified time. Lambert's problem gives the two-burn solution for a rendezvous, but it is generally not optimal.

Optimization: The optimizer uses gradient-based methods to minimize fuel use. Given an initial set of burn locations and times, it uses derivatives of the cost function—fuel usage—to find a minima. The gradient sees only local behavior, and cost function can be complicated. Therefore, we need the initial guess to be close to the global optimum.

Initial Guess: Currently we make an initial guess by varying the point at which the satellite leaves the first orbit and where it enters the second orbit. We use Lambert's problem to estimate the fuel required and arbitrarily set the location and number of intermediate burns.



MMS and the Magnetosphere

Magnetosphere: The activity in the Earth's core makes it into a large magnet, and its field—called the magnetosphere—extends far into space. The solar wind shapes the field lines, pushing them near the Earth on the day-side and extending a long tail outwards on the night-side. The magnetosphere traps plasma from the solar wind. Studying the dynamics of the magnetosphere teaches us about not only the Earth but also plasmas, which make up 99% of the matter in the universe.

Magnetosphere MultiScale (MMS): The Magnetosphere MultiScale mission will study the small-scale plasma processes that transport, accelerate, and energize plasmas in thin boundary and current layers in the Earth's magnetosphere and study how they affect large-scale phenomena. A constellation of four satellites will allow scientists to differentiate between spatial and temporal changes. MMS has four phases to study different parts of magnetosphere, from the day-side magnetopause to the night-side storms. Highly elliptical orbits will optimize the tetrahedrality of the formation around the apoapsis.

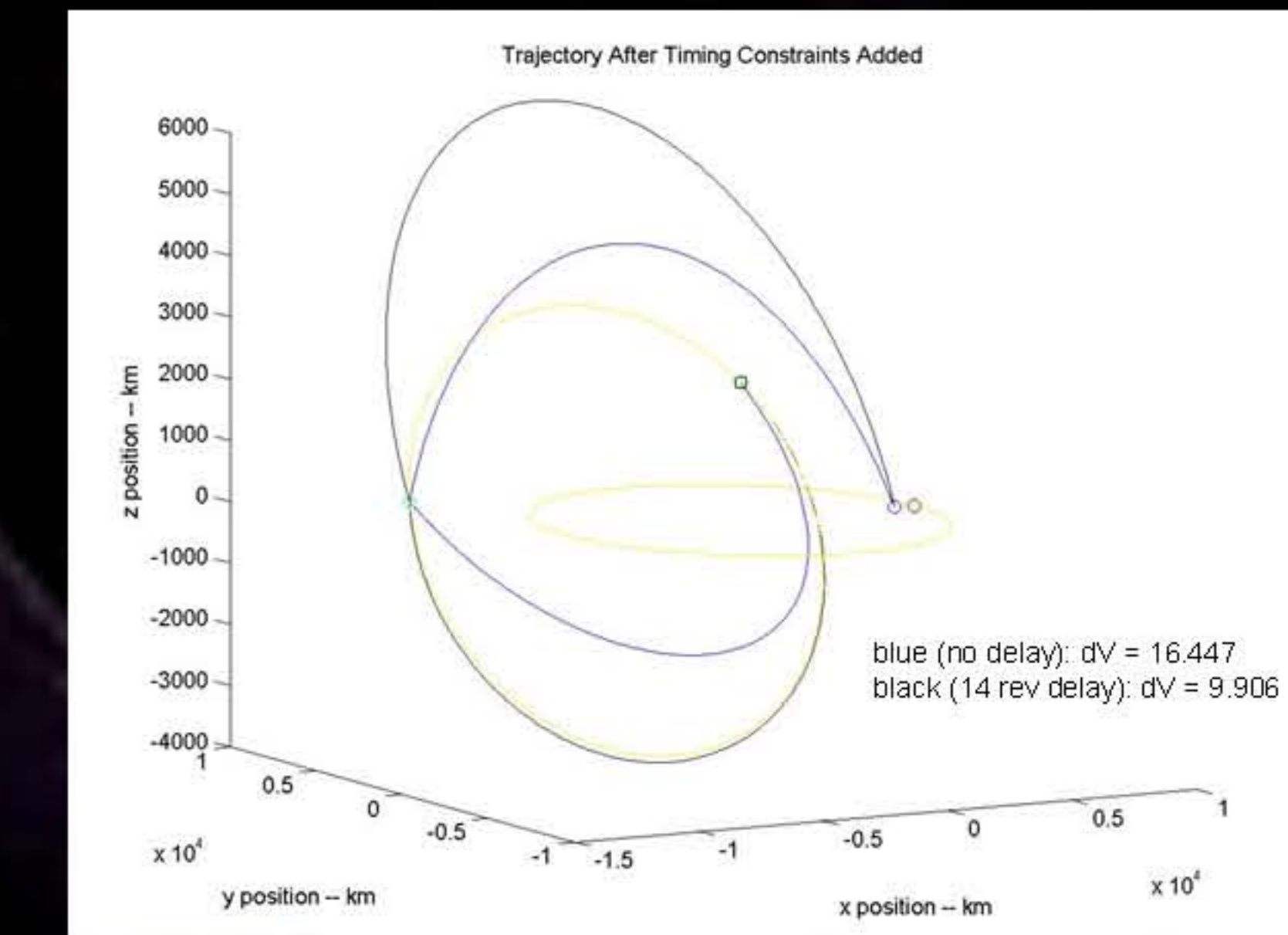
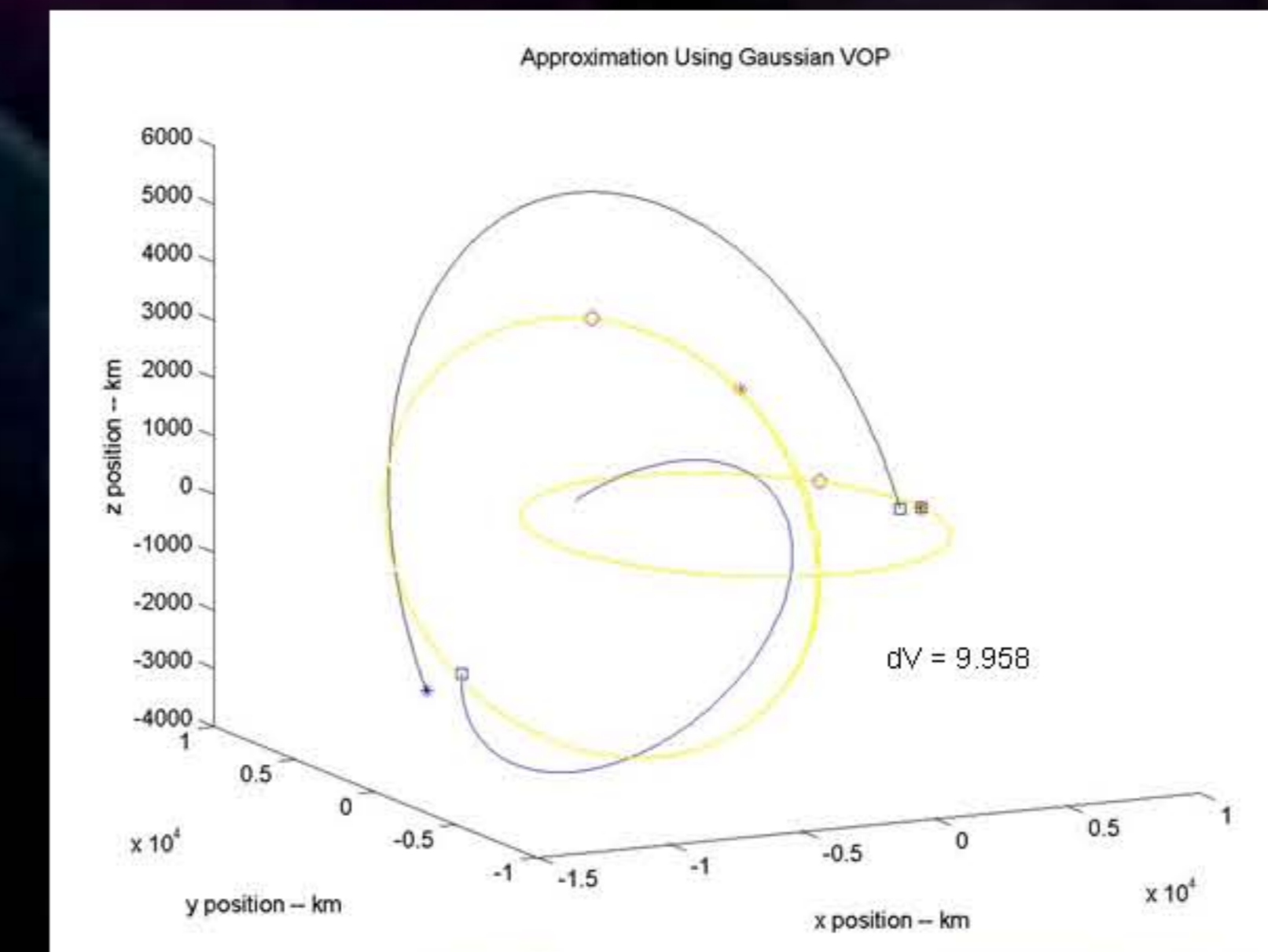
Minimum Fuel Rendezvous for Formation Flight

Finale Doshi, 2004 NASA Academy Research Associate, MIT 2005

Principal Investigator: Steven Hughes, Aerospace Engineer, Code 595

Initial Guess Algorithm

To quickly create good initial guesses, we try picking intelligent burn locations and fit them to the problem constraints. We tested some sample cases with two and three burn cases before and some changes in two or three orbital elements, the following algorithm is being implemented in Matlab.



User Inputs

- Starting orbit, location, time
- Ending orbit, location, time
- (optional) Maximum transit time, maximum revolutions, departure window, arrival window

Schaub* and Alfrend's Application of Gaussian Variation of Parameters (VoP)

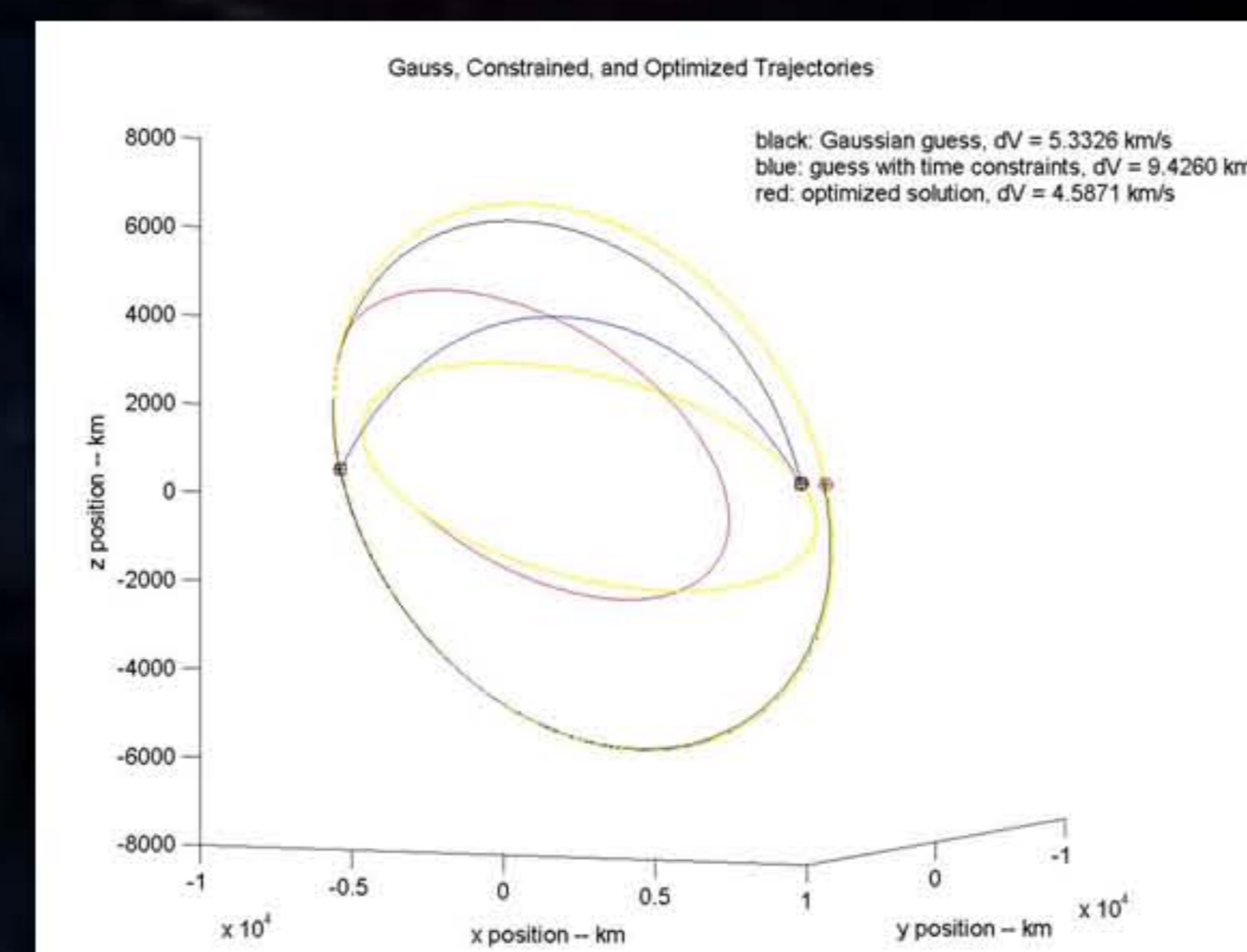
Gauss's variation of parameters is a set of differential equations that describes how the six orbital elements change when perturbed by a force. Schaub and Alfrend use these equations to first order and propose a method to make near-optimal corrections for small orbital changes. We use this approach to choose burn locations and times for general orbital changes. (Partially implemented)

Constraint Fitting

Because Schaub method is designed for small orbital corrections, the endpoints must be forced to fit the desired rendezvous. Next, burn locations and times are adjusted to fit the optional constraints. If the time window is large enough, the algorithm will try delays and phasing orbits to find a guess that closely matches the Gaussian approximation. (Partially implemented)

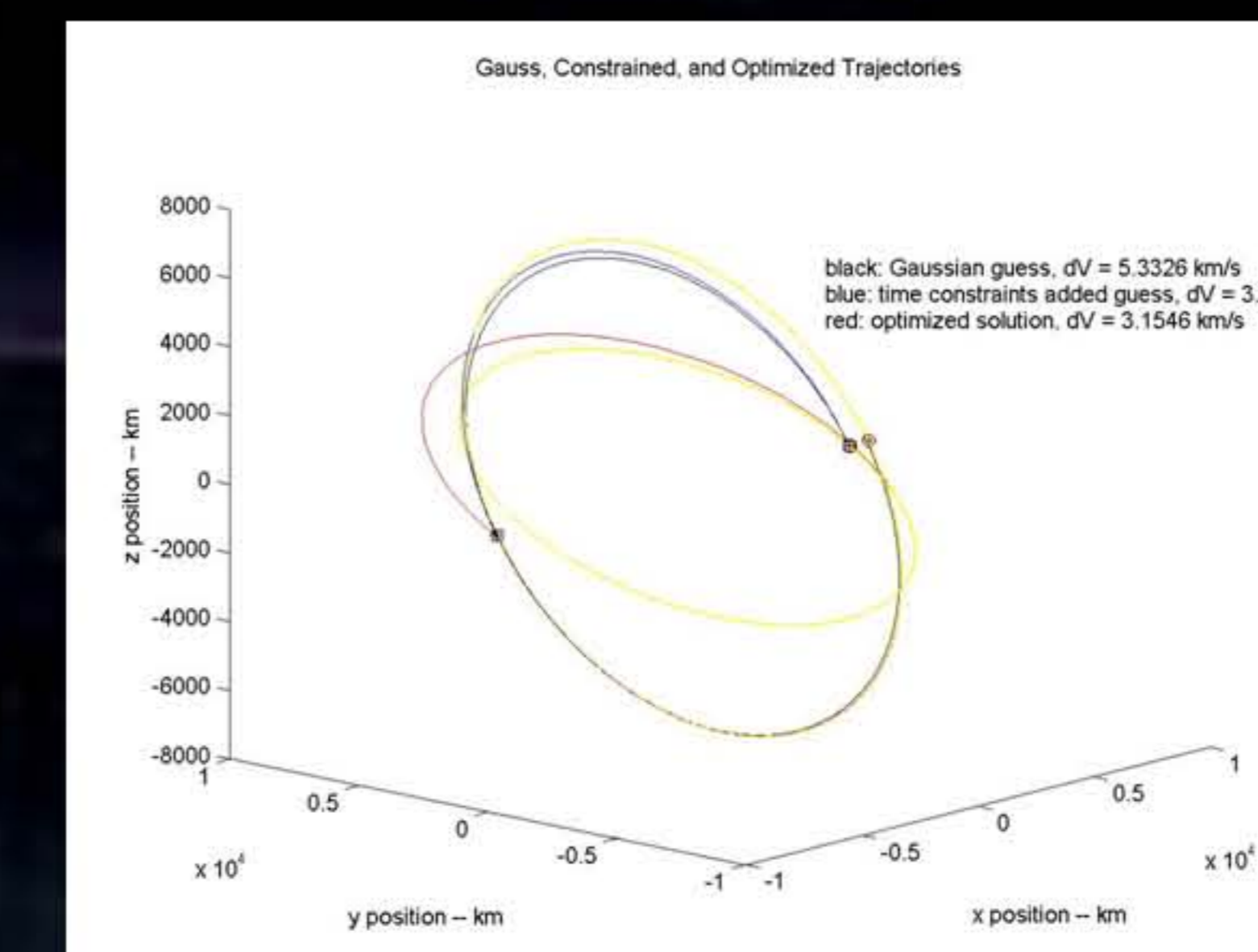
Apply Lambert's Problem: Finally, we apply Lambert's problem to calculate the change in velocity required on each leg. This provides a reference for comparison with the optimized solution. (Implemented)

Ill-fitted Case



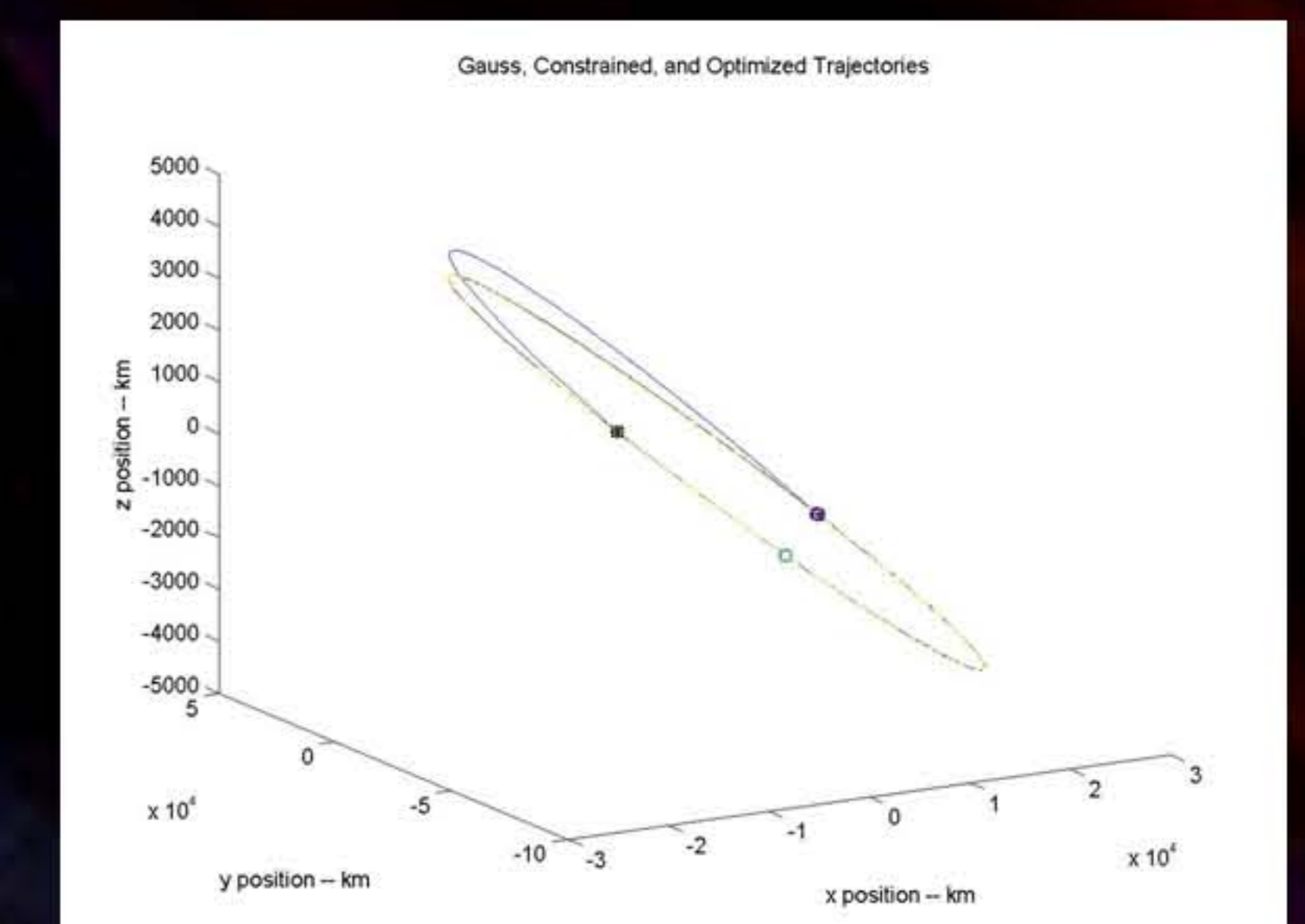
Very suboptimal guesses are created when hard time constraints are forced on the Gaussian VoP.

Well-fitted Case



The algorithm produces a much better guess when given a larger rendezvous window.

MMS Case



Closely matched Gaussian VoP and constrained guesses for the MMS case suggests a good guess.